

S U P P L E M E N T

A paper presented by Mr. S. A. Akhter, Superintending Engineer, Dhaka Electric Supply Authority, Dhaka, Bangladesh, at a symposium sponsored by the Zoological Society of India and held at Zoology Department, Burdwan University, Burdwan, West Bengal, India, on 28.9.95 is reproduced below for the purpose of drawing attention of students of Biological sciences. At the end of the article we offer additional information on certain points raised in the text..... EDITOR

Thermodynamics of life

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Abstract :

The paper deals with the concept of energy and work dynamics of animals. Both in mechanical heat engines and live animals hydrocarbons are burned to produce heat and to convert to work. Heat engines obey the laws of thermodynamics. The writer presumes that animal systems also do the same. The energy work relationship is same in both the cases. Precisely, all the energy consumed is not converted to work, depending on difference of temperature, some heat is and must be rejected. There must be two reservoirs of heat; one at higher temperature and the other at lower one. Normally all energy passes from higher to lower temperature. For existence, animal life must have higher temperature than its surroundings; work output and amount of heat rejection depend on the difference of this two temperatures.

The study of thermodynamics evolved primarily to explain and explore the theoretical background of heat engines. This included small auto engines to giant steam-turbines. However the scope broadened to define and understand energy and work relation in a more detailed way.

Interestingly this theory applies to animal life as well. Every moving animal is a heat engine and obeys all laws of thermodynamics. In the following account an endeavour will be made to piece together the information that has been gathered and to focus on the relationships between energy

input and useful work. There might be loopholes and errors. It is left to experts to revise and to further the horizon.

A heat engine receiving some heat energy in various forms (food in case of animals, fuel in case of mechanical engines), converts the energy to produce work. But all the energy is not converted. Some heat energy is and must be lost. In the ideal cycle the heat engine operates between two temperatures—a high and a low temperature. The higher one is called Source (being the source of energy input) the lower being Sink (receiving rejected heat). Consider a steam-engine using super-heated steam of 150°C and rejecting the steam at an atmospheric temperature say 25°C . The ideal efficiency of this engine would be $1 - T_{\text{Sink}}/T_{\text{Source}}$, where $T_{\text{Sink}} = (273^{\circ} + 25^{\circ})\text{K}$ and $T_{\text{Source}} = 273^{\circ} + 150^{\circ}\text{K}$. So the equation becomes $1 - 298/423$ i.e., $1 - 0.704 = 0.2955083$ i.e., 29.55% only.

In human being the body temperature of 37°C i.e., $37^{\circ} + 273^{\circ} = 310^{\circ}\text{K}$ and atmospheric ambient temperature (say) 25°C i.e., $(273^{\circ} + 25^{\circ}) = 298^{\circ}\text{K}$ may be taken as Source and Sink temperatures respectively. The theoretical maximum efficiency in this case would be 0.0387097 i.e., 3.87%. So if a man burning say 2500 Calories (1 Cal = 1000 cal), his effective maximum use will only be 96 Calories. This is the maximum work output, available theoretically. Real work, internal, and external, will be less. This reveals, as a thermodynamic engine, how inefficient the human being is! However all calories are not same. Protein calories producing more temperature are superior to fat calories in producing work. Because protein, burning as glucose has proportionately more carbon than hydrogen than fat, Carbon burning produces more temperature and as such will produce more work. However efficiency calculation is not that straightforward. Rejection of energy is more important. There are other forms of heat rejection too. Artificial sinks are created with the help of external energy to reject heat. The basic source of external energy is Sun.

The higher temperature T_{Source} is Source temperature, in this case the body temperature. The lower temperature T_{Sink} is Sink temperature, in this case the ambient temperature. In order to get work of 96 calories the body must reject heat energy equivalent of $2500 - 96 = 2404$ calories. If the body cannot reject necessary amount of heat, it ceases to work and that amounts to death. In case when ambient temperature rises above body temperature or becomes equal to it, the work output becomes “-ve” or “0”. That is body ceases to function and man would die. But it does not occur, because animals have other mechanisms of rejecting heat.

Perspiring (insensible perspiration), air-current (convection) etc. are amongst them. However if he cannot reject heat, he will eventually pass away. This is known as heat stroke. Perspiring allows latent heat of evaporation to be taken away. An athlete perspires a lot after an arduous physical activity. Long distance runners are acquainted with the term 2nd wind when athletes get extra energy. At that time T_{Source} of an athlete rises, heart beat increases to pump extra energy. At the end of exhausting work he perspires a lot and his heart beat slows. That is why sometimes normal heart beat of an athlete comes down to as low as 37 or 38 per minute.

In case of animals requiring large convertible energy, say migratory birds, flying thousands of miles develop high body temperatures sometimes around 60°C . In this case the thermal efficiency will be $1 - (273 + 25)/(273 + 60) = 0.105$ i.e., 10.5% approximately 3 times higher than that of human beings. It can be observed that with same amount of calorie intake birds get 3 times more

work than human beings. But it changes when the bird is relaxing. Even ordinary flying birds are known to have relatively higher body temperatures than non-flying ones. When walking or resting, their Source temperatures decrease to produce less work required during normal period. During heavy exercise human beings increase their body temperature by a degree or two and reduce during extreme cold. This happens to increase the efficiency and in the latter case to protect from excessive heat loss. There is also diurnal variation of temperature in each 24 hours of the day. The maximum body temperature reaches at around 4 o'clock in the afternoon and minimum around 4 o'clock in the morning. The variation is around 1°C . Human beings also increase their temperature during exigencies, when they require more energy. This happens in case of fever, when someone is attacked by external agents.

Here comes the most interesting case. In case of parasites, their Sink temperature T_{Sink} is Source temperature T_{Source} of human being. In case of fever when human Source temperature increases parasites have difficulty in heat rejection causing their heat-death. So higher temperature in case of fever is really propitious for cure of disease and it should not be reduced with analgesics unless required. Parasites are supposed to have higher body temperature than their hosts. Experiments are however required to ascertain this point. Temperature measurement of minuscule creatures is difficult, presumably infra-red techniques or other modern precision techniques may be used.

It follows, if ambient temperature is much less than human body temperature, the human parasites will die due to excessive heat loss unless they can make necessary adaptive changes in their Source (body) temperature encoded in their genes. Active life may be defined as production of heat energy and its part rejection in the ambient temperature. However in the egg stage there is no heat transfer. Life remains in dormant stage. Initially some heat from higher temperature Source is required to hatch the egg. As soon as the egg is hatched it starts to produce heat on its own and exchanges with the ambient temperature Sink.

It appears that as soon as the heart beat of an infant starts, a baby in mother's womb shall have more temperature than the amniotic fluid of mother's womb. If this not true, than the foetus cannot be called living. A great ethical question of abortion (whether a human life is destroyed) as a method of population control can be resolved this way. If a foetus has the same temperature as the amniotic fluid, it is not a life as yet, If higher, it is. However, it is to be investigated, how and when the temperature of foetus increases over the temperature of amniotic fluid surrounding it.

Before the advent of Pasteurization, milk was boiled to destroy bacteria. The boiling temperature destroyed chemical properties of bacteria and killed it. But this high temperature also destroyed some useful ingredients of milk too. Without knowing the thermodynamic principles, Louis Pasteur applied this to cause heat death of bacteria without altering chemical properties of milk. Pasteurization of milk is a process where bacteria are not directly killed by heat. Here the Sink temperature (temperature of the milk) is raised to a certain level. When kept at that level for a considerable period, it becomes impossible for the bacteria to reject heat. Consequently the bacteria die a heat death.

Animal life can also be defined, as a system where heat is produced, the temperature is raised from its environment and major part of the heat is lost to the environment and minor part is converted to work. An interesting case evolves when human sperms or blood is kept in sub-zero temperature

for a long time, when no heat exchange takes place. It is supposed to be dead. But life revives after temperature is raised, just like car engine being switched off or on. This evidences that life can go into dormant stage and return back. We have seen muscles of slaughtered animals twitch hours after the death of the animal. This suggests that individual units of life may exist within human/animal body other than the total life itself. We can also deduce that there are different temperature zones in human or animal systems. Each isothermal zone defines a life unit. A certain life's boundary is defined by a certain temperature.

Otherwise life within life would not have been possible. This shows that human life really is a conglomerate of lives controlled by one superior life called intelligence. Intelligence is basically an bio-electrical activity to be discussed later in a separate article.

One question of cold-blooded animals may be analyzed. Fish and reptiles are cold-blooded animals. Due to buoyancy (Archimedes' law) the fish do not require to carry its body weight. Therefore work requirement is less. So T_{Source} is less consequently producing less work. The snakes having no feet almost carries entire body weigh on the earth as such requires less work (but greater than the fish). Their body temperature is also low. This shows, body temperature is increasing with the increased need of work.

From the equation stated earlier, it is evident that people of colder and drier countries should have greater efficiency and consequently should be more active. History evidences that territorially aggressive people are mostly from colder or drier countries. It has been observed that territorially aggressive people are more animal keepers than agrarians. This indicates that extra energy develops a tendency to dominate others.

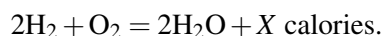
An interesting point of global warming due to green house effect may be considered. Say, global temperature increases by 1°C from 25°C (assumed in the earlier example) to 26°C . The resultant efficiency will be $1 - 299/310 = 0.0354639$ i.e., 3.54%. This shows the resultant work output will decrease by 8.52%. Actual loss may be bigger, because work for internal consumption will vary less and output work will be more drastically reduced. This should be concern of environmentalists.

Nevertheless, if animals can be compared to heat engines then trees can be compared to refrigerators. The refrigerator follows the same cycle as the heat engine but in a reverse direction. In a refrigerator heat is pumped from lower to higher temperature. Normally, according to 2nd law of thermodynamics, it would have been impossible. But 2nd Law of thermodynamics has one concession. Aided by external energy heat can go from lower to higher temperature. In refrigerator this external energy is supplied by electrical energy which drives the compressor. In case of plants, CO_2 is converted back to $\text{C}_6\text{H}_{12}\text{O}_6$. It means the spent up fuel CO_2 is recycled back to burnable carbon from which work can again be extracted. Wherefrom the external energy is derived? It comes from sun rays and photosynthesis is the process of recycling the energy.

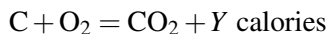
Had the recycling not been there, all the energy would have passed from higher to lower grade either performing or not performing work. Finally only single stable temperature would have existed rendering life in this planet impossible. It also suggests, that during evolution, plant life came first and made the atmosphere possible for animal life in this planet.

Life scientists appear to depend more on chemistry than on physics. But life really is as much

physics as chemistry. All chemical combinations and dissociations take place with producing or absorbing heat. The suggested way of introducing a chemical equation to a student may be:



or



This energy should be taken into account. The carbon atom in carbon dioxide (CO_2) and carbon atom in glucose ($\text{C}_6\text{H}_{12}\text{O}_6$), are not the same so far energy is concerned. We cannot extract energy from CO_2 but we get energy from glucose. Same thing can be said about hydrogen and other elements. Chemical combinations are changes of states of energy of atoms. If the role of energy is perceived properly, the dynamics and hitherto undisclosed knowledge about life, may reveal itself to bio-scientists. Rather physics should have its right place in biological sciences.

These observations are not really scientific in strict sense. Sometimes some observations are oversimplified. Real things are much more complicated. But it shows one way of understanding life and researchers may well develop new frontiers. Say, global temperature (T_{sink}) rise suggests that we are burning more fuel than can be reprocessed by plants. We can straightaway state that as *Homo sapiens* can little change their body temperature (T_{source}) they are physically inferior species; with the change of global temperature they will be annihilated much before other animals (like dinosaurs). However human being is the most intelligent species, may be we may not have to worry that much!

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Editorial note

I. Heat relationships between the so-called ‘cold-blooded animals’ and their environment :

The temperature of the medium is necessarily lower than that of a metabolising cell/organism occurring in the medium. For example, according to Seymour (1972) the mean temperature of all measurements of basking toads was 30.9°C , while that of toads hopping about in the experimental set-up was 25.8°C and that of toads in the shade was 19.5°C while the wet bulb air temperature remained at 15°C throughout the entire period.

Also, according to Prosser (1973) muscles of a 40 gm fish showed a temperature of 0.44°C above

that of environment.

According to Hill and Wyse (1988), in frogs, snails and many insects body temperature may not approximate the ambient temperature, which is determined by totality of thermal conditions of environment. Body temperature will be elevated by heat radiated by sun well above the ambient temperature, but evaporation of water from body surface of animals will depress temperature of body a few degrees below the ambient temperature. Hill and Wyse (1988) also pointed out that organisms radiate only at infrared wave-lengths.

II. Heat relationships between the parasite and the host :

According to Weir (1983) pyrexia is a protective response against invading microbes. For example, gonococci are readily killed above 40°C. Also, before the introduction of antibiotic treatment 'fever therapy' was a common treatment of gonococcal infection. Human lymphocytes cultured at 39°C shows enhanced response to streptococcal products and plant haem agglutinins than when cultured at lower temperature.

Heat relationship between parasite and the host was also known to the ancients. According to Lee T' Ao (1953) as early as in 582 A.D. San Ssu-Miao wrote the '*Thousand Gold Remedies*' mentioning therein that a man whose fire element was not harmonious would be steaming hot in his whole body.

It has been further learnt by us from some Tibetan monks that heat therapy was practised by Tibetan physicians in the following way:

Specific herbal concoctions for treating particular disease was heated in containers of appropriate size and then the hot container was applied to the affected portion of the anatomy directly, so that herbal properties would pass into the diseased area along with the passage of heat, effecting a cure.

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